N73-26090

THE POSSIBILITIES OF MAKING QUANTITATIVE EVALUATIONS OF THE FUNCTIONING OF CLOSED PEOPLE-OPERATOR CONTROL SYSTEMS

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ABSTRACT. The three tasks comprising the specific sections of the general methodology for evaluating ergatic systems are reviewed.

The Moscow Institute of Electronic Machinebuilding has, in recent years, been working on methods for making quantitative evaluations of the functioning of control systems in which people-operators take part. Let us conditionally call ergatic any physical system requiring the participation of man, regardless of the degree of such participation [3, 8]. Systems containing manipulators too are ergatic, the specifics of which consists of special organization of input signals to the operator. However, no particular organization of the operator's sensor field will change the principal features of the system as a whole; it has present in it a man-operator with a gamma of properties distinguishing him from the automatic device. The latter is what predetermines the research methods used. /148

Eragtic systems are more sharply defined types of adaptive systems capable of changing their structure and parameters in accordance with adaptation to operating conditions. The adaptive features of ergatic systems show up in two ways. First, the characteristics of the man-operator change during the instruction process to learn the actions to be taken to perform a specific task within the framework of a particular system. Here adaptation plays a positive role, because it takes in the system as a whole, and because the efficiency of operator performance (and hence the efficiency of the system as a whole) is increased during the instruction process. Second, the characteristics of the man-operator can change with his adaptation to the effect of external disturbances. The adaptive properties of the organism are mobilized for life-support purposes, however, and system efficiency can be reduced as a result.

The man-operator in an ergatic system often is looked upon as some sort of linearized link, as in [13], for example. But this fails to include the adaptability of the ergatic system at the same time that no proof is required of changeability of the properties of the man-operator affected by favorable, or

unfavorable factors. The need to consider the adaptive features of the operator is emphasized in papers by psychologists and researchers dealing with technical problems that include the "human" factor [4, 5].

This article will review the three tasks comprising the specific sections of the general methodology for evaluating ergatic systems. The first task is that of evaluating the degree of adaptivity of the man-operator during his instruction on how to work as part of the particular system. The second task is that of synthesizing the man-operation function described for a known level /149
of his adaption as part of the particular system. The third task involves making a quantitative evaluation of the probability of the operator performing a series of logical operations under stress.

These tasks permit building an ergatic system, the circuit of which is "operator instruction - synthesis of his model and the use in this case of a developed technique for system optimization - evaluation of stress in the system and recommendations for system modernization."

Let us represent ergatic system classification on the basis of criteria applicable when manipulators are used in these systems.

Reference [8] classifies ergatic systems in terms of number of operators, the degree to which the operator participates in system operation (in the system performing its basic task), appearance of the communication between operator and object of control and degree to which the system is hierarchical. Classification by the first three criteria is meaningful for ergatic systems with manipulators.

Ergatic systems can be broken down into monoergatic, one operator, and polyergatic, when the number of operators is more than one. However, one must distinguish monoergatic systems with back-up operators, needed to increase system dependability. Important to note here is that one operator takes part directly in performing the task assigned to the system. The organization of the sensor field for each succeeding operator in polyergatic systems depends significantly on the results of the actions taken by the preceding operator. Flow lines for assembling radio sets, and the like, are example of such systems. Systems with manipulators basically are monoergatic systems.

Ergatic systems are broken down into first and second type systems,

according to the degree of continuity of participation of the operator in causing the system to do its job. Ergatic systems of the first type can be characterized by the indirect participation of the operator in causing the system to do its job. The system (object) itself can be nonergatic and capable of independently performing its basic task. A nuclear reactor is such a system. But in the event of a failure, or for whatever reason, the object ceases to perform, the operator goes into action, the end purpose of which is to put the object back to work. In this case the operator is performing a monitoring function, looks for faults, and restores the system. But if the man-operator participates directly in causing the system to perform its basic task as its controlling link, we have an ergatic system of the second type. This is a follow-up system in most cases. According to the classification given in [13], these systems can be broken down into compensating (in which the mismatch between the required and actual positions of object coordinates is supplied to the operator's "input"), following (in which the mismatch signals and the coordinate values are supplied to the operator's "input"), and predicting (in which the operator works with a series of repeating signals and, by predicting the behavior of the object, introduces a predicting control signal). Systems with manipulators are, for the most part, ergatic systems of the second type.

Ergatic systems have two types of classification with respect to how the operator communicates with the object. The first includes so-called ergatic systems with direct communication, in which we shall conditionally include manipulators, and for which the operator is the energy source. We shall conditionally include systems with telemetry communication, and in which the manipulators have an independent power supply in the second type of ergatic systems. /150

Thus, systems with manipulators can be classified as monoergatic systems of the second type with direct, or telemetry, communications.

Some of the methods that can be used to make quantitative evaluations associated with investigation of systems with this classification characteristic are listed in what follows.

The operator, during the instruction (training) process should acquire skill in fixing the coordinates of the object he is controlling and in correctly

distributing the control actions in order to change these coordinates in accordance with instructions. This distribution of control actions is "metered" according to the information received by the operator, and is called metering. The correctness of the metering of the control actions by the operator of an ergatic system will depend on the quality with which he converts the information he has received on the behavior of the object of control. The conversion of the input information is made by the man's sensory organs, and the resulting action is a motor response, so these processes are included among the sensor-motor type of assignments. There are many cases when object control with the aid of manipulators is a process of following some random mismatch for which it is necessary to compensate. So there are many cases when these processes can be classified as compensator follow-up.

The operator, in the case of compensator follow-up, attempts to reduce the mismatch, $\varepsilon(t)$ to zero. Each realization of the follow-up process is some function of follow-up, usually continuous. The follow-up function enables us to determine the behavior of the object and, as a result, of the system as a whole. The follow-up function adequately reflects the results of the motor activity of the operator in an ergatic system in the case of continuous sensor-motor assignments.

Clearly, each special control task is limited by predetermined requirements and going beyond the limits means that the task is not carried out. And because the follow-up functions characterize the quality of operation of an ergatic system with predetermined precision, we may speak of some zone of acceptable values of realization of these functions.

All realizations of the follow-up function should be in this zone, one we shall call the acceptable control zone. If the follow-up function goes beyond the boundaries of the zone it means the man-operator in charge of the control action (motor response) had made an incorrect metering.

Research conducted in carrying out a number of engineering-psychology tasks [5, 9, 10, 13] has revealed that the man-operator reacts not only to the input signal, to the mismatch signal $\varepsilon(t)$, but also, albeit to a lesser degree to its first derivative $\dot{\varepsilon}(t)$. We can, in this case, write the canonical equation of form

The follow-up function has some scatter, limited by the zone of its acceptable values, so that the parameters of Eq. (1) can change within a predetermined range. The latter is, in turn, interrelated with the range of change in the function. Let us use the phase plane concept, that is, the plane determined by the coordinates of system error ϵ (the abscissa) and its derivative $\dot{\epsilon}$ (the ordinate). The acceptable control zone now can be expressed in terms of the phase representations in the form of an area of acceptable positions for the points represented in the phase plane. The coordinates of each of these points will be the value of the mismatch between the required and current coordinates of the object, ϵ, and its derivative, $\dot{\epsilon}$. Our phase plane then can be considered to be the plane of estimates of the follow-up lines, which are the phase analogues of the follow-up function. /151

Follow-up, as a process of establishing continuous corrections to the follow-up function mismatch, is subordinate to statistical laws because the control signal in an ergatic system depends on the degree of instruction given the operator, and the latter depends on the individual characteristics of the person being instructed. Moreover, even in a control process performed by an operator we have a gamma of random activities that are caused by external disturbances, as well as the potential of the man included in the system for controlling signals (noise) from the central nervous system. This noise is always present when man is controlling a system, and this sometimes leads to representing the operator in the form of a random signal generator. So it follows that the process reviewed can and must be investigated using probability methods [9].

Naturally, we can have only information in some degree or other associated with the functions $\dot{\epsilon}(t)$ and $\epsilon(t)$ cited above during the operating training process. It therefore is of interest to associate the components of the follow-up function with some instructional probability measure.

Let us postulate the existence of some neuropsychological apparatus for generalized evaluations, use of which compiles information on the results of the sample metering performed in the compensating follow-up process. The

operator classifies the results into two incompatible groups: successful, and unsuccessful. The quantitative measure of success then can be determined as the ratio of the measure of the subset of successful samples to the measure of the set of all samples taken at the particular moment in time. The relative share of successful samples (of controls) can be determined with sufficient accuracy for practical use by the ratio of the length of the segment of the follow-up line included in the limits of the acceptable control zone, to the total length of the follow-up line. The lengths emerge as sets, or subsets. This permits confirming that the phase plane $\{\varepsilon, \dot{\varepsilon}\}$ is the plane of evaluation.

Thus, change in the state of the learning system can be expressed by some variable which we shall call the information variable, numerically equal to the relative share of successful samples in the set of samples taken for the given time segment and for the given conditions.

Change in the information variable during the organism training process can be postulated by the following mathematical scheme

(2)

where

$y(n + 1)$ is the value of the information variable after the $(n + 1)^{\text{th}}$ sample;

$\varkappa(n + 1)$ is a random magnitude, taking the value +1 if the sample is successful, and -1 if it is not.

The recurrent Eq. (2) permits forecasting each current value of y from the preceding values and proceeding from the specified sample (the learning sequence).

Eq. (2) can be interpreted in Bush and Mosteller operators [2]

(3)

Here Q_1 and Q_2 are the known Bush and Mosteller operators; that is /152

(4)

Reference [9] points out that in this case operators for which $\alpha_1 = \alpha_2 = \alpha$; $\lambda_2 = 0$ can be taken.

The region of possible values of the parameters α and λ can be determined such that $0 \leq y(n) \leq 1$, and what follows then is that $0 \leq \alpha \leq 1$; $0 \leq \lambda \leq 1$.

Using mathematical induction we can show that the following expressions for the n-tuple application of the operators Q_1 and Q_2 to the intial value of the information variable (the apriori state of the organism) is valid

(5)

Then it can be shown, as was done in [9] for example, that in the case of the (n + 1)-tuple application of the operators Q_1 and Q_2, the following expression are valid.

$$\left.\begin{aligned} Q_1^{(n+1)}y(0) &= \alpha Q_1^{(n)}y(0) + (1-\alpha)\lambda_1; \\ Q_2^{(n+1)}y(0) &= \alpha Q_2^{(n)}y(0). \end{aligned}\right\} \tag{6}$$

As a result of the approximation of the obtained difference equations with differentials, let us write the resultant expression for the information variable in the form

(7)

when the point represented is within the limits of the region of possible controls, and in the form

(8)

when the point represented is beyond the limits of the region of possible controls.

Information as to the dynamic features of the object of control serves as the basis for constructing the region of possible controls. If, for example, it is necessary to compensate for some initial mismatch ε_0 (Figure 1), we can do so only providing that the follow-up function is contained within some acceptable region, if (and this must be particularly emphasized!) the compensation is to be made with the required precision and at the required time, T_D.

It then is possible, based on knowledge of the dynamic features of the object of control (that is, of the possible boundaries of values ε and $\dot{\varepsilon}$ which can be achieved by the given object on the basis of its physical features), to form region D, limited at the time coordinates by the boundaries of the follow-up functions 1 and 3 (Figure 1a). Boundary and acceptable follow-up functions in the time region can be given as the analogue of the corresponding functions in phase coordinates (Figure 1b). The region of acceptable controls, region D, will be the hatched field.

Figure 1. Boundary trajectories of follow-up functions. a - in coordinates ε and t; b - in coordinates $\dot{\varepsilon}$ and ε. 1 - minimum and 3 - maximum follow-up boundary functions; 2 - normal acceptable follow-up function in the time region; T_D is the finite control time (cycle); ε_0 is the initial mismatch value.

Compensating follow-up experiments have established some set of representative points $F(\varepsilon, \dot{\varepsilon})$ which, naturally, should be compared in value of coordinates with the boundary values for the D region. In sum, what is created is the possibility of activating the apparatus of linear operators Q_1 and Q_2, and as a result to obtain the information variable y(t) (Figure 2).

Because the y(t) value obtained corresponds to the finite (in the particular sample) ratio of the lengths of the corresponding trajectories, it can be shown that at the end of the sample the value of the information variable has its probability converge with that of the representative point remaining in the D region. And because the D region, by convention, is constructed to include the dynamic features of the object, no difficulties arise in limiting the set of possible values of the coordinates of the representative point, because taking

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the representative point beyond the limits of the D region clearly means non-fulfillment of the assignment in the particular sample. Consequently, the probability of the representative point remaining in the D region is an adequate probability that the ergatic system will carry out the assigned task.

Thus, the probability of the representative point remaining in the D region permits evaluation of the dependability of the ergatic system if the adaptation process will be carried out as a result of the specified conditions and in a specified time interval.

Eqs. (7) and (8) readily yield an automatic computer solution. The use of an automatic computer to solve the problem of quantitative evaluation of the degree of adaptation is particularly important because instructing operators in complex actions (pilots, and others, for example) takes place in trainers which are none other than analog modeling devices integrated with real equipment. If the values of the mismatch, ε, its derivative $\dot{\varepsilon}$, the boundary value for the mismatch, ε_D, and the corresponding value of the derivative $\dot{\varepsilon}_D$, are inserted in the block diagram of the modeling (Figure 3), we can obtain the value of the information variable immediately. The unit for evaluating this variable (Figure 3) also is based on an operation amplifier (integrator) 6, for solving Eqs. (7) and (8). The switches in Figure 3, K, are needed to set the sign of the input variables ε, $\dot{\varepsilon}$, ε_D, $\dot{\varepsilon}_D$; that is, to determine the quadrant in which the evaluation is being made.

The information variable values obtained can be produced in temporal coordinates, as well as in the phase plane. What are obtained in this case are individual evaluations in terms of the mismatch (Figure 4) and of its derivative.

Indications to the operator of the value of the information variable during the instruction process provide for the introduction of new feedback for use in obtaining information on the quality of control over the entire range from T_0 to T_D. Clearly, this cannot help but react favorably on accelerating instruction and increasing its quality. Savings in control cycles were 35% during the experiments in instructing operators of ergatic systems of the class reviewed. /154

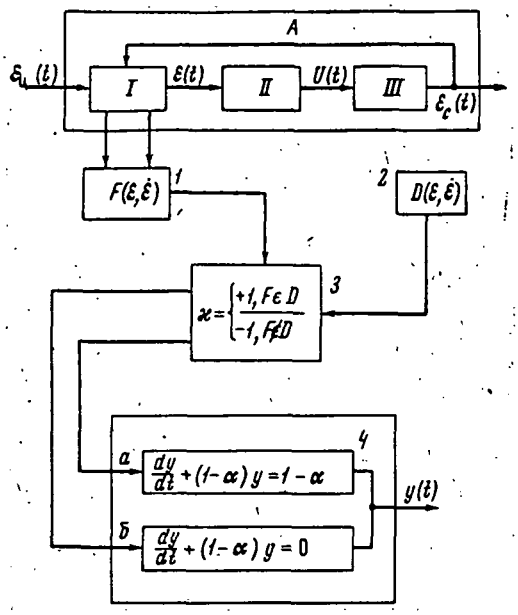

Figure 2. Block diagram for the evaluation of the information variable in the cycle of instructing the operator of an ergatic system of the second type. A - ergatic system; I - indicator; II - man-operator; III - object; 1 - formation of set of inputs; 2 - formation of set of possible controls (D region); 3 - unit for evaluating the random magnitude $\varkappa$; 4 - unit for evaluating y(t).

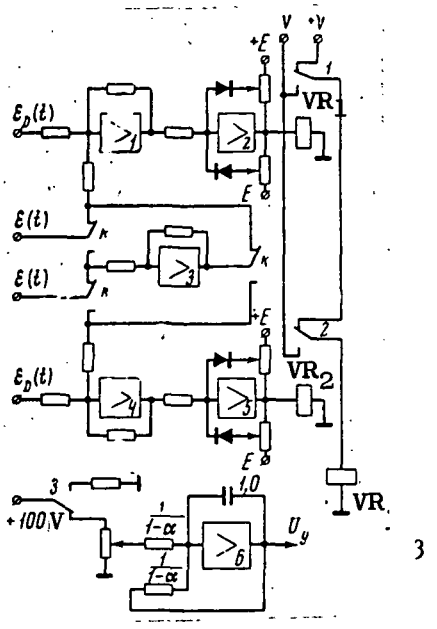

Figure 3. Block diagram of modeling of the process for evaluating control success. 1, 2, 4, 5 - operation amplifiers selecting the modulus of input magnitudes; 3 - inverter; VR_1 and VR_2 - relays in circuits of corresponding input magnitudes for specified boundary values; VR_3 - relay for putting data in the unit for evaluating the information variable of the instruction.

Figure 4. Typical recordings of the process of evaluating success of control. 1, 2, 3, - numbers of recordings as success decreases; ε_{DK} - boundary functions of the mismatch; ε_K typical acceptable mismatch function (system errors); T_D - time of cycle.

Some function $\mu(N)$, where N is the number of control cycles completed for purposes of instructing the operator, and μ is the final value of the information variable y(t) for each cycle, results from the determination of the value of the information variable in each cycle. This will provide the instruction curve, and the value of the probability of successful completion by the operator of the specified task will correspond to each cycle. This is

significantly different from the often used evaluation of instruction in terms of frequency of successful controls, determined for a group of cycles. In such case /15
the probability of a successful control is determined for a group of cycles. If, in the method proposed, the statistical collective is reduced to one control cycle, the hypothesis as to the constancy of the operator's qualities can be extended here to only the time of one control. Just how much more correct this approach is, as compared to evaluation in terms of frequency, where this hypothesis could be extended to the group of control cycles studied, is clear.

The degree to which the operator is trained can be classified as that system condition to which the stabilized level of the instruction curve corresponds.

Only after the degree of adaptation in an ergatic system has been determined can we proceed to possible approximations in the system, such as, for example, a mathematical description of the operator for a concrete time segment and for definite control conditions.

There are two ways to obtain the man-operator describing function in an ergatic system of the second type; by selecting the values of the parameters for some hypothesized structure, and by purposeful movement to the optimum relationship between the output variable models and the operator tested. The latter, naturally, is the more acceptable, because the selection of possible values for the parameters of some structure is quite lengthy.

It is proposed that the methods of the theory of sensitivity [1] be used to synthesize the parameters of the operator's describing function in an ergatic system of the second type.

References [8, 10, 12] suggest methods for evaluating the criteria of sensitivity for different types of systems, based on the fundamentals of the general theory of sensitivity developed by M. L. Bykhovskiy [1].

Let us understand system sensitivity to mean its capacity to change its quality criteria with change in parameters. The coefficient of influence is the system sensitivity criterion and is the partial derivative of some system index in terms of a given parameter, taken for the rated value of the parameter. Let us stipulate that the system index to investigate is the mismatch γ between the output function for the man-operator and his model.

Let us take some generalized scheme of an ergatic system in which all elements are replaced by some linearized structures. Let us find first of all the coefficient of influence for the parameters of these linearized structures (of the transfer functions for the units) of magnitude $\epsilon(t)$, which is a function of the error for the particular scheme.

Differentiating the transfer function for a closed system in terms of each of the parameters, and aware that each of the transfer functions is a polynomial relationship, we find the equation for the coefficient of influence in the form

(9)

where

$F_1(s)$ is the transfer function for a closed system in terms of the output magnitude $y(s)$;

$F_2(s)$ is the transfer function for a closed system in terms of the error $\epsilon(s)$;

$\partial\epsilon/\partial q_i$ is the unknown derivative (the coefficient of influence);

$[W_{in}(s)]_{g_i}$ is the influence operator, some linear structure (transfer function) formed in accordance with definite rules.

Reference [8] gives a rule for forming the influence operator when the parameter q_i is the cofficient of the polynomial in the numerator, and the denominator is the transfer function for the particular unit. So if q_i is the coefficient of a polynominal in the numerator of the transfer function for some unit $W_i(s)$ the corresponding influence operator will take the form /156

(10)

The influence operator takes the following form for q_i, which is the coefficient of the polynomial in the denominator of the transfer function $W_i(s)$

$$[W_{in}(s)]_{b\psi} = -\frac{s^{\psi}}{B_i(s)}. \tag{11}$$

The general rule for finding the reference operators can be expressed in the form

$$[W_{in}(s)]_{q_i} = \frac{\frac{\partial W_i}{\partial q_i}(s)}{W_i(s)}. \qquad (12)$$

So the method used to find the coefficients of influence is called the influence operators method.

The influence operators method provides all needed coefficients of influence simultaneously if all needed influence operators are formed and if, as has been done in Figure 5, a system for making the evaluation has been constructed in accordance with Eq. (9). Automatic computer units can be used to realize the influence operator for different cases. The signal x(t) is random, so in essence the coefficients of influence are random processes. The statistical characteristics of the coefficients of influence must be determined in this case.

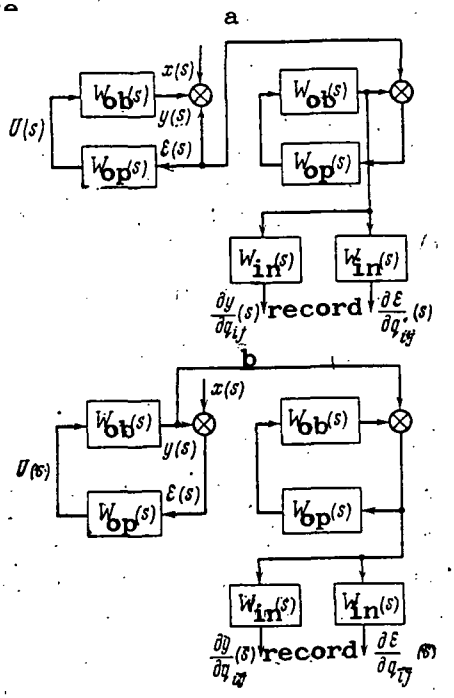

Figure 5. Generalized block diagram of the obtaining of coefficients of influence. a - variant using error signal; b - variant using output signal from controlled object.

Optimization (synthesis) of the operator function described is in terms of the criterion

(13)

where

(14)

$\varepsilon^*(t)$ is the index of the operator model.

Each new value of the criterion h is found from

$$h_i = h_{i-1} - k\frac{\partial h}{\partial q_i}, \qquad (15)$$

where

k is the step of change in h.

The coefficient of influence of form $\partial h/\partial q_i$ is associated with the coefficient of influence of form $\partial \varepsilon/\partial q_i$. As a matter of fact, if we differentiate (13) with respect to q_i we find

(16)

The influence operators method is very convenient to use to synthesize the real operator in a system. In point of fact, operators taking the course of instruction on a system of a given type to solve a given task can be used in place of $W_{op}(s)$ in order to realize the scheme shown in Figure 5. The scheme then, naturally will more precisely reflect the real status of the operator in the follow-up process. The error in evaluation; the result of scatter in operator characteristics, drift in those characteristics in terms of time, and inaccuracy in the influence operators models, is, in the final analysis reflected in the error in the coefficient of influence; that is, in errors of a second and higher order of smallness. /157

Reference [12] cites derivations of influence operators for nonsteady-state models of describing functions. The influence operator will have the following form for the parameter $q_i(t)$ contained in the polynomial in the numerator of the parametric transfer function $W_i(s, t)$ as a coefficient

$$[W_{in}(s, t)]_{a_\varphi(t)} = \frac{s^\varphi}{B_i(s, t)}; \qquad W_i(s, t) = \frac{A_i(s, t)}{B_i(s, i)}. \tag{17}$$

For the parameter $q_i(t)$, contained as a coefficient in the polynomial in the denominator of a nonsteady-state describing function (linear)

(18)

The derivations of Eqs. (17) and (18) are based on the structural conversions of the nonsteady-state models of sensitivity into linear variable systems [6, 7].

References [8, 10] have presented the bases for building an integrated sensitivity model, and it is used in [10] to synthesize a linear describing function for a man-operator in an ergatic system of the second kind. The

difference between the integrated model of sensitivity and the influence operators is that the latter need no reswitching in the system, or taps from it of any internal signals, for their realization, whereas taps are needed to build the integrated model. What are formed are two artificial auxiliary signals, making it possible to receive simultaneously all the unknown coefficients of influence using simple, universal, analog equipment. The economic effectiveness of the integrated model is much higher than it is for the influence operators method.

As experiment, making possible a comparison of the evaluation of the instruction given the operator in an ergatic system of the second type using different criteria is of interest, for it uses the criterion of success, as well as stabilization of the level of change in parameters of the describing function and the level of change in the error at the output during the training process (Figure 6).

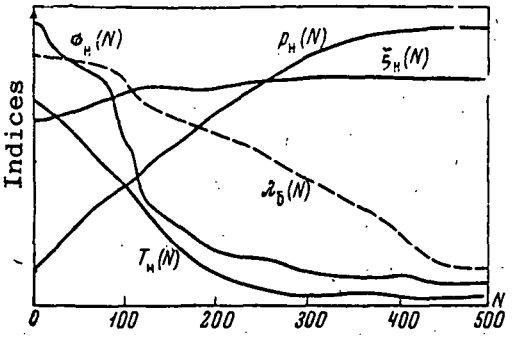

Figure 6. Comparative evaluation of stabilization of levels of parameters for instruction and model of the operator. $\sigma_H(N)$ change in system error; $P_H(N)$ - change in the probability of performing the task in the control process; $\xi_H(N)$ - change in the damping of the operator describing function during instruction; $T_H(N)$ - change during instruction of the time constant for the operator in an ergatic follow-up system; $\lambda_\sigma(N)$ - change during instruction of the intensity of the biopotentials from the flexor muscles of the hand; N - cycles of control.

The complexity in evaluating the quality of the work done by the operator when there is an increase in the percentage of logical operations in the total number of subtasks should be noted. It is of particular importance to evaluate the probability characteristics of the quality of the operator activity in an ergatic system of the second kind acting under stress conditions [11, 14].

Let us call stress the state of an ergatic system characterizing the intensification of the processes circulating in it under the influence of factors that are external with respect to the system.

Let us agree to distinguish two types of stress.

1. Q-stress - that state of the system caused by an increase in the physical load (amplitude of vibration, frequency and brightness of an input video signal on the scope, acoustic noise, weightlessness, climate, and others). It can be characterized by an increase in intensity, or by the occurrence of new input influences in the ergatic system.

Equipment and mechanism operating modes in the machine part of an ergatic /158
system are complicated by the effects of Q-stress factors, the rate of component failures increases, and so on. The levels of intensity of biopotentials in the man-operator rise, muscle cramping and tremors appear, metering of strength is upset, stiffness of posture and movements appears, pulse and respiration change, as does the electrical conductivity of the skin, and so on [5].

2. S-stress - that state of the system caused by the reactions of the man-operator to change in the psychological factors involved in the process, including change in standby time to perform certain subtasks (operations). In other words, S-stress is the consequence of the occurrence of a time deficit in the system. This type of stress is characteristic only of an ergatic system.

We noted above, in the course of determining the degree of adaptation, and the operator describing functions, that <u>conditions for cooperation</u> between man and machine were not violated in the process of the functioning of an ergatic system. Stress factors however, can violate those conditions.

Clearly, then, evaluation of stress in an ergatic system will permit designing in such a way that the conditions of cooperation will be maximized in terms of some criterion selected in advance.

Let us consider the evaluation of the efficiency of an ergatic system when S-stress is acting.

It is only in an ergatic system under stress (time deficit condition) that it is possible to accelerate the work tempo when there is an increase in labor efficiency. In point of fact, the time deficit, up to some level, is an

organizing factor for the operator. Once the threshold of stress is reached, however, the time deficiency acts negatively on the probability of performing the task, and the efficiency with which the system functions is reduced.

The magnitude

(19)

where

T is the total time assigned for the completion of all tasks;

T_i is the time already used to complete the i^{th} preceding subtasks;

i = 1, 2, ..., n;

$\bar{T}$ is the mean time needed to perform (n - i) successive subtasks, provided the operator works at average speed and without errors,

is a qualitative measure of the S-stress.

Reference [14] cites classifications of levels of urgency in completing tasks in accordance with which stress evaluations are made, and determination of the probability of the ergatic system performing its task.

1. There is no requirement for urgent performance of a subtask if the time /159 remaining is, on the average, sufficient to perform all subsequent subtasks.

But all subtaks are completed that the operator can break down into essential and nonessential. The condition for lack of urgency can be expressed in the form

$$\sum_{j=i}^{n} \bar{t}_j \leqslant T - T_i, \tag{20}$$

where

$\bar{t}_j$ is the mean time to perform the i^{th} operation (j = i, ..., n).

2. Urgent completion is necessary if there is not enough time to complete all succeeding subtasks, but completely adequate to perform essential subtasks. The urgency condition then can be expressed as

(21)

but

(22)

Here, as before, S = 1.

3. Special urgency of completion of a subtask may be required if remaining time is not sufficient to perform essential subtaks.

Then S > 1.

A series of expressions of the form [11]

(23)

where

M is the threshold of stress S;

$\bar{p}_i$ is the mean probability of completing the i^{th} subtask,

can be used to calculate the factual probability of the ergatic system completing its task.

An algorithm for calculating the time to complete each of a series of successive subtasks, as well as the probability of completing these subtasks, has been developed. Figure 7 is a typical task completion probability to stress level relationship.

Figure 7. Typical ergatic system of the second type task completion probability to stress relationship.

Evaluation of stress in an ergatic system is an important adjunct to the methodology of evaluations of the degree of adaptation and of the describing function.

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